Collaborations and Partnerships in NASA's Earth Science Data Systems

Hampapuram K. Ramapriyan[1,2] and Kevin J. Murphy[3]

[1]Science Systems and Applications, Inc. USA; [2]NASA Goddard Space Flight Center, USA; [3]NASA Headquarters, USA

Corresponding author's e-mail address: Hampapuram.Ramapriyan@ssaihq.com

AUTHOR INFORMATION (optional):

A short biographical statement from the author(s) may be placed after the title page information. This must be no longer than 200 words and include only information relevant to the subject matter. This will be moved to before the reference list in the final publication.

Hampapuram Ramapriyan is a Research Scientist/Subject Matter Expert at Science Systems and Applications, Incorporated (SSAI). He supports the ESDIS Project at NASA GSFC through its contract with SSAI. The ESDIS Project is responsible for archiving and distributing most of NASA's Earth science data using EOSDIS, which is a major core component of NASA's Earth Science Data System Program. Ramapriyan's primary focus is data stewardship and preservation. Prior to his employment with SSAI, he was the Assistant Project Manager of the ESDIS Project. His responsibilities included management of Science Investigator-led Processing Systems that processed and delivered data to the EOSDIS Distributed Active Archive Centers (DAACs) as well as being the data liaison between the ESDIS Project and the Principal Investigators of the projects under the MEaSUREs (Making Earth System Data records for Use in Research Environments) Program. He is an active member of several of the Earth Data System Working Groups (ESDSWGs), and chairs the Data Quality Working Group, which is one of the ESDSWGs. As an active member of the Federation of Earth Science Information Partners (ESIP) since 1998, he is currently the Vice-Chair of its Data Stewardship Committee and Chair of the Information Quality Cluster.

Kevin Murphy is Program Executive for Earth Science Data Systems at NASA HQ. In this capacity Mr. Murphy manages a portfolio of programs encompassing the Distributed Active Archive Centers, Science Investigator-led Processing Systems and a number of competitively funded programs. Prior to assuming his current role Mr. Murphy served as System Architect for EOSDIS, conceived, developed and managed major system development projects that including near real time systems, search engines, large scale visualization system and Earthdata.nasa.gov. Murphy has received numerous awards during his NASA career, including the NASA Exceptional Achievement Medal, Robert H. Goddard Exceptional Achievement for Engineering, Charles S. Falkenberg Award, among others.

Abstract

NASA has been collecting Earth observation data from spaceborne instruments since 1960. Today, there are tens of satellites orbiting the Earth and collecting frequent global observations for the benefit of mankind. Collaboration between NASA and organizations in the US and other countries has been extremely important in maintaining the Earth observation capabilities as well as collecting, organizing and managing the data. These collaborations have occurred in the form of: 1. NASA's developing and launching spacecraft and instruments for operation by other agencies; 2. Instruments from collaborating organizations being flown on NASA satellites; and 3. Instruments from NASA being flown on satellites from collaborating organizations. In addition, there are collaborations such as joint science teams, data exchanges, and participation in international organizations to promote interoperability of various data systems. The purpose of this paper is to describe some of the Earth science data-related collaborative efforts in which NASA participates, and highlight a few results relevant to Earth system science research obtained through such collaborations.

Keywords: Data systems, Earth science, Collaboration, Interoperability, Standards, Remote sensing

Introduction

NASA has been collecting Earth observation data from spaceborne instruments since 1960 when the first experimental weather satellite, called the Television Infrared Observation Satellite (TIROS-1), was launched in collaboration with the Department of Defense. Today, there are tens of satellites orbiting the Earth and collecting frequent global observations for the benefit of mankind. In addition to satellite missions, airborne as well as land- and ocean-based instruments are contributing to the wealth of measurements of geophysical properties contributing to the understanding of the Earth as a system. Collaboration between NASA and organizations in the US and other countries has been extremely important in maintaining the Earth observation capabilities as well as collecting, organizing and managing the data. The purpose of this paper is to describe some of the collaborative efforts in which NASA participates, and highlight a few results pertinent to Earth system science research obtained through such collaborations.

Interagency and International Collaborations

We observe that of the over 100 missions listed on the NASA web site on Earth science missions (http://science.nasa.gov/earth-science/missions/), approximately 37% involve interagency collaborations within the US (DoD, DoE, NOAA, and USGS), and 27% involve international collaborations (Argentina, Belgium, Brazil, Canada, ESA, EUMETSAT, Finland, France, Germany, India, Italy, Japan, Netherlands, Russia, Switzerland, and the United Kingdom). These collaborations have occurred in the form of: 1. NASA's developing and launching spacecraft and instruments for operation by other agencies; 2. Instruments from collaborating organizations

being flown on NASA satellites; and 3. Instruments from NASA being flown on satellites from collaborating organizations. In addition, there are collaborations in the form of joint science teams, data exchanges, aircraft flights for collecting Earth science data, ground based field campaigns including those for validating satellite-derived data products, participation in international organizations such as the International Council for Science (ICSU) World Data System (WDS), Committee on Earth Observing Satellites (CEOS) and the International Standards Organization (ISO).

NASA's Earth Science Data System (ESDS) Program

NASA's ESDS Program supports several activities, most of which involve collaborations in some form or another. The key "core" component of this program is the Earth Observing System Data and Information System (EOSDIS). The Earth Science Data and Information System (ESDIS) Project at NASA's Goddard Space Flight Center is responsible for the development, maintenance and operation of EOSDIS. The EOSDIS consists of 12 Distributed Active Archive Centers (DAACs) spread across the United States, and is a collaborative effort involving four NASA Centers, the US Geological Survey, the US Department of Energy and four universities. Each DAAC archives and distributes data products in a specialized set of Earth science disciplines. EOSDIS has been in operation since 1994, and has been providing data to the global user community following the free and open data policy that NASA put in place in 1990 with the start of the EOS Program. During the year ending in September 2015, EOSDIS distributed over 1.4 billion files of data (over 11.7 petabytes) to users in 240 countries.

In addition to EOSDIS, the ESDS Program supports two "community" data system programs – and Advancing Collaborative Connections for Earth System Science (ACCESS) and Making Earth System Data Records for Use in Research Environments (MEaSUREs). The projects under these two programs are selected by peer-review of proposals in response to periodic calls as a part of NASA's Research Opportunities in Space and Earth Sciences (ROSES).

The purpose of the ACCESS Program is to "enhance, extend, and improve existing components of NASA's distributed and heterogeneous data and information systems infrastructure" through research by a number of Principal Investigators. Several of the technologies developed in the ACCESS Program may be deployed within EOSDIS as they are matured.

The purpose of the MEaSUREs Program is to produce long-term, consistent "Earth System Data Records (ESDRs)" defined as "a unified and coherent set of observations of a given parameter of the Earth system, which is optimized to meet specific requirements in addressing science questions". Climate Data Records (CDRs) are a particular case of ESDRs. Following the first call for proposals from the MEaSUREs Program in 2006, 30 projects were selected. Currently there are 27 active projects under the MEaSUREs Program, which were selected following the second call in 2012. The input data used for generating the ESDRs in most of these projects are obtained from multiple satellites under international collaborative arrangements. Figure 1 shows

the numbers of MEaSUREs projects receiving inputs from various countries. The designation "International" in this figure indicates either activities such as the International Satellite Cloud Climatology Project (ISCCP) or organizations such as the European Space Agency (ESA).

<<Figure 1 Caption: Number of MEaSUREs projects using input data from various countries or international organizations>>

The ESDRs generated by the MEaSUREs Principal Investigators are archived and distributed by the DAACs in their respective disciplines. Many of the ESDRs have been included in the Essential Climate Variables Inventory (http://ecv-inventory.com/ecv2/) maintained by the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS) and the World Meteorological Organization (WMO).

The collaboration between the core and community components of the ESDS Program occurs through the Earth Science Data System Working Groups (ESDSWG). Individual working groups within the umbrella of ESDSWG are formed to address key technology and information system issues. They provide recommendations to the ESDIS Project regarding specific capabilities of data and information systems for the benefit of the community. They address various challenges, issues, and opportunities in response to data system priorities and community-identified needs. They also develop guidelines and best practices that address the practical implementation of standards and technologies, enhance data interoperability, and improve software development and software architecture practices. Currently there are 10 active working groups considering a varied set of topics: metadata for airborne investigations, atmospheric science users' forum, data quality, dataset interoperability, geospatial web services, data visualization, OPeNDAP implementation best practices, search relevance, software citations and time series.

Members of the ESDIS Project and the DAACs take an active role in the Federation of Earth Science Information Partners (ESIP), which is an organization with over 180 members from several government agencies, universities, non-profit organizations and commercial entities. The mission of ESIP is "to support the networking and data dissemination needs of its members and the global Earth science data community by linking the functional sectors of observation, research, application, education and use of Earth science". Within ESIP, collaboration areas are formed to address technical and other issues of common interest. There is some commonality and overlapped membership between NASA's ESDSWG and the ESIP collaboration areas, even though their functions and scopes are different. There is a two way exchange of information on best practices in various technical areas for the benefit of all the participating organizations.

NASA's ESDS Program takes an active role in interagency activities such as the US Global Change Research Program, US Group on Earth Observations, Big Earth Data Initiative, and the Networking and Information Technology Research and Development (NITRD) Program.

Also, internationally, the ESDS Program is active in the Committee on Earth Observing Satellites (CEOS) Working Group on Information Systems and Services (WGISS), the Group on

Earth Observations (GEO) Data Sharing Working Group, the International Standards Organization (ISO), and the Open Geospatial Consortium (OGC). The ESDIS Project is a Network Member of the ICSU/WDS, and nine of the 12 DAACs are Regular Members of the ICSU/WDS. All these collaborations promote increased interoperability of various data systems, increased utility of data held by many organizations, and adherence to standards.

Examples of Datasets Resulting from Collaborations

In this section we briefly describe some of the many EOSDIS datasets, which have resulted from interagency/international collaborations, and which are useful for research in several Earth science disciplines. A few examples of MEaSUREs ESDRs are included, as well as one from the EOS Terra mission, resulting from a collaboration between Japan and US.

MEaSUREs ESDRs

Rignot et al (2011) have developed an ESDR called "MEaSUREs Antarctic Grounding Line from Differential Satellite Radar Interferometry". A grounding line is "the transition boundary where ice detaches from the bed and becomes afloat in the ocean". It is "critical to ice sheet mass budget calculations, numerical modeling of ice sheet dynamics, ice-ocean interactions, oceanic tides, and subglacial environments." This ESDR uses data from the Earth Remote Sensing Satellites 1 and 2 (ERS-1 and ERS-2), RADARSAT-1, RADARSAT-2, and the Advanced Land Observing System Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) for years 1994 to 2009.

Rignot et al (2012) have developed an ESDR called "MEaSUREs InSAR-Based Ice Velocity Maps of Central Antarctica: 1997 and 2009". Information about ice velocity is essential for estimating mass balance of glaciers and ice sheets and in studies of ice dynamics. This ESDR consists of two high-resolution digital mosaics of ice motion in Central Antarctica, assembled from satellite interferometric synthetic-aperture radar (InSAR) data acquired by RADARSAT-1 in 1997 and by RADARSAT-2 in 2009.

Joughin et al (2015) have developed an ESDR called "MEaSUREs Greenland Ice Sheet Velocity Map from InSAR Data". It contains ice-sheet-wide velocity maps covering much of the Greenland ice sheet for winters of 2000/2001 and 2005/2006. The ESDR is derived from InSAR data obtained by RADARSAT-1, the Advanced Land Observation Satellite (ALOS), and the TerraSAR-X satellite. According to Joughin et al (2010), "Comprehensive mappings such as these, at regular intervals, provide an important new observational capability for understanding ice-sheet variability."

Using data from TOPEX/Poseidon, Jason-1 and OSTM/Jason-2, Beckley et al (2015) have developed global mean sea-level trends for the period covering September 1992 to present. These data are updated with a time lag of up to 4 months. Accurate computation of mean sea-level is critical to understand climate change effects, and determination of the orbital positions of

the satellites precisely is essential to achieve the necessary accuracy. Precision orbit determination in turn requires many globally distributed, international resources including the Global Navigation Satellite Systems (GNSS).

Kwok has generated ESDRs with measurements of ice motion, deformation, ice age and thickness, and backscatter histogram. The ESDRs cover the period of fall 1997 to May 2008 using RADARSAT-1 data from the Canadian Space Agency and are available from the Alaska Satellite Facility DAAC. The products cover the Arctic basin, with the most consistent coverage over the Western Arctic Basin. (Kwok 2016)

The JPL Multiscale Ultrahigh Resolution (MUR) MEaSUREs Project, led by T. Chin generates level-4 sea surface temperature analysis with four-day latency and also a near-real-time dataset with one-day latency. The current version (version 4) of the MUR analysis is based on nighttime Group for High-Resolution Sea Surface Temperature (GHRSST) L2P skin and sub-skin SST observations from several instruments (AMSR-E from Japan on NASA's EOS Aqua satellite, MODIS on NASA's EOS Terra and Aqua satellites, US Navy microwave WindSat radiometer, Advanced Very High Resolution Radiometer (AVHRR) on several NOAA satellites, and in situ SST observations from the NOAA iQuam project. (JPL MUR MEaSUREs Project, 2015)

Kim et al (2013) provide a global record of the daily freeze/thaw (FT) status of land areas derived from satellite observations of radiometric brightness temperatures. Two records are provided: (1) Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imager (SSM/I) record for the years 1979 to 2010 and (2) Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) record for the years 2002 to 2011. "The landscape freeze–thaw (FT) signal from satellite microwave remote sensing is closely linked to vegetation phenology and land–atmosphere trace gas exchange where seasonal frozen temperatures are a major constraint to plant growth." (Kim et al, 2012).

In a project called the "Global Ozone Chemistry and Related trace gas Data records for the Stratosphere (GOZCARDS)", Froidevaux et al (2015) have focused on hydrogen chloride (HCl), water vapor (H_2O), and ozone (O_3). The resulting dataset is a long-term global ESDR of monthly zonal mean time series starting in 1979. This dataset is of high relevance to studies of ozone decline and recovery, for understanding changes in atmospheric composition and for constraining model representations of atmospheric dynamics and photochemistry. Data from instruments on-board several NASA satellites and the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) on the Canadian satellite SCISAT are used as inputs.

ASTER GDEM

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) is another example of a very useful dataset resulting from international collaboration. The release of Version 2 of this dataset was announced jointly by the

Ministry of Economy, Trade, and Industry (METI) of Japan and NASA in October 2011. This dataset is a contribution from METI and NASA to the Global Earth Observation System of Systems (GEOSS).

Summary

NASA has been collecting Earth science data using observations from spaceborne and airborne instruments as well as through field campaigns for several decades. The observing missions as well as the data system activities needed for gathering, processing, archiving and distributing the data and derived products require collaborations. NASA collaborates with universities, commercial entities, agencies within the US as well as other countries and international organizations. This paper has shown several activities benefiting from such collaborations and illustrated some scientific products useful for Earth science research that have resulted from collaborative sharing of data.

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Competing Interests

The authors declare that they have no competing interests

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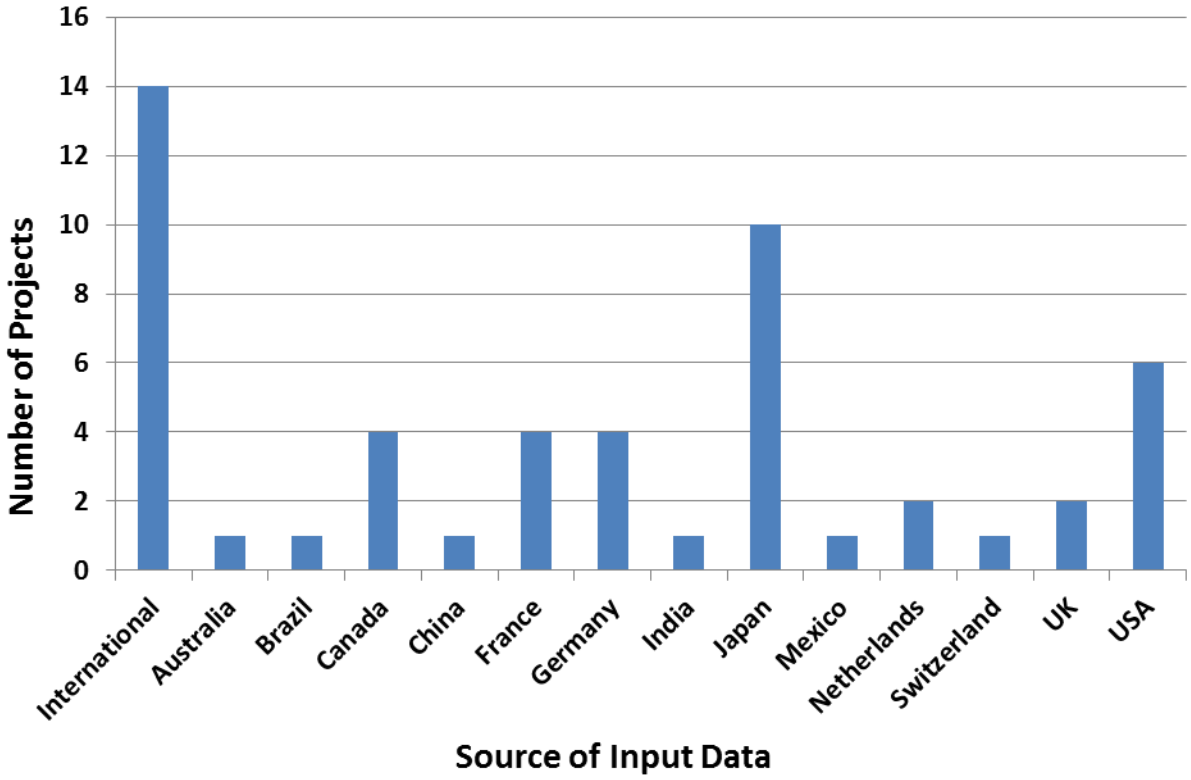
Figure 1


16
14
12
10
8
6
4
2
0
Number of Projects
International
Australia
Brazil
Canada
China
France
Germany
India
Japan
Mexico
Netherlands
Switzerland
UK
USA
Source of Input Data